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DISCUSSION OF FLOOD-CONTROL OPERATION OF TENNESSEE VALLEY AUTHORITY RESERVOIRS

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By Ray K. Linsley, Jr., and Edward J. Rutter

HYDRAULICS DIVISION

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DISCUSSION

RAY K. LINSLEY, JR.,[4] Assoc. M. ASCE.—Well organized and factual, Mr. Rutter's summary of the operation of an extensive reservoir system for flood-control purposes is a definite contribution to the field of hydraulic engineering. The literature contains many papers dealing with the construction of dams, but very few papers on the equally important subject of their operation.

Under the heading, "Operation of Main-River Reservoirs for Maximum Possible Reduction," the author very properly calls attention to the large difference between the actual reservoir operation and the "ideal" operation which would effect the maximum possible stage reduction at the point or points to be protected. He also emphasizes the fact that the "ideal" operation is almost impossible to accomplish because it presupposes a perfect knowledge of future stream flow. However, many projects for flood control, power, irrigation, and other purposes have been justified on the basis of benefits computed on the assumption of perfect operations. This overestimate of the benefits could well turn the balance between justification and rejection for projects with a low cost-to-benefit ratio.

Errors in river forecasting occur because the forecaster must work with data which cannot be measured with precision and with relationships which almost never quite attain perfect correlation. These sources of error will not frequently introduce serious error into forecasts prepared by competent forecasters if precipitation does not occur subsequent to the forecast. Despite extensive studies by meteorologists, high accuracy in weather forecasting has not been attained. The ordinary newspaper weather forecasts for 24 hours in advance verify with an accuracy of about 80%. Considering only forecasts of rain or forecasts made during rainy periods, the percentage of accuracy would probably be found to be somewhat lower. However, these forecasts, even if perfect, would be far from adequate. The river forecaster must know how much rain will fall, when it will occur, and how it will be distributed over the basin. For areas such as the Tennessee Valley the forecast must extend from 3 to 10 days into the future, depending on the current situation.

If a competent meteorologist can study a specific basin carefully and then discuss his forecast directly with the water control engineer, his advice will be found to have great value. Nevertheless, on many occasions reserve storage must be set aside as a safeguard against the unexpected and the ideal operation becomes impossible.

The eighth paragraph under the heading, "Peak Reductions," raises an interesting point. It is indicated here that potential damage to property built subsequent to the program of the Tennessee Valley Authority (TVA) is included in the estimated benefits of the several operations. If it can be assumed that the builders of these properties had possible alternative locations that would

NOTE.—This paper by Edward J. Rutter was published in May, 1950. The numbering of footnotes in this Separate is a continuation of the consecutive numbering used in the original paper.

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have been safe from flood, then the sites must have been selected with the assurance that they would be protected by TVA operations. Can such properties be properly included in the estimates of benefits from flood-control operations? If they are included, should not any future flood damage to these properties be charged as a cost of TVA operations rather than as the cost of unavoidable natural losses?

It would be interesting to have an indication of the probable error in the computed natural flows. Although the reduction in stage at Chattanooga (Tenn.) resulting from the operations is so large that any reasonable error would not materially affect the picture, the reduction claimed at Cairo (Ill.) is not far greater than the errors that might be expected in such involved computations. The determination of stage at Cairo from flows on the Ohio, Tennessee, and Mississippi rivers is probably subject to an error of several tenths of a foot. The error to be expected in the determination of the natural outflow from the Tennessee River would be difficult to estimate without the detailed computations. It would not be impossible for this error also to amount to several tenths of a foot in terms of the Cairo stage.

There are two sources of error in the computations which would tend to make the computed natural flows too high. First, the computed local inflows include the flow derived from rainfall on the surfaces of the reservoirs and, hence, are higher than would have occurred under natural conditions. Second, the accelerating effect of the reservoirs would tend to yield local inflows somewhat higher than under natural conditions. It is possible, of course, that these effects are negligible, but if they have not been investigated they should be.

EDWARD J. RUTTER,[5] M. ASCE.—Several questions pertinent to the flood-control operation of a large reservoir system have been raised by Mr. Linsley's discussion. Two points are of particular interest, one related to flood benefits and the other to accuracy of natural flow computations.

At Chattanooga, in floods occurring since the first reservoir came into operation, estimated benefits include damage to property in existence on the date of the flood, rather than only damage to property in existence before the first reservoir came into operation. Mr. Linsley suggests the possibility that development subsequent to the TVA program was built on land selected over possible alternative locations that would have been safe from flood. It is doubtful whether such alternative locations were available, because of topography, zoning restrictions, poor highway and railway connections, and the unavailability of municipal services. Moreover, complete protection against the maximum probable flood, or even the maximum known flood, is not provided by the reservoirs, and a flood hazard still exists at Chattanooga. The city has been repeatedly warned of this situation, as have individuals and industries seeking flood-height information from TVA. It cannot be stated, therefore, either that alternative building sites safe from flood were available, or that sites were selected with the assurance that they would be protected by TVA operations. The writer believes it is correct to determine benefits on the basis of the status of the city at the date of the flood.

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Mr. Linsley also questions the accuracy of natural outflows determined from inflows which, in turn, were computed from changes in reservoir levels. As stated by Mr. Linsley, there are two possible sources of error in this method: (1) The increased runoff from the greater water surface area of the reservoirs compared with that from natural land area; and (2) the difference in timing of the runoff attributable to the use of flat-pool storage in the tributary reservoirs. The determination of inflows by flow-storage curves eliminates this source of error in the main-river reservoirs.

The effect of greater runoff from a larger water surface area is believed by the writer to be negligible. In the case of Norris Reservoir, which has a relatively large water area with respect to its total drainage area, the water area at the level when the rain occurred in January, 1946 (approximate El. 980), is 20,000 acres or 31 sq miles. This is only slightly more than 1% of the total drainage area of 2,912 sq miles. If it is assumed that there would be 100% runoff on the increased water area instead of 70%, the increased runoff from the entire area would be 0.3%. Such an error could be ignored, of course, considering the accuracy of flow measurements in general.

To determine whether the second possible source of error was significant, computations of natural discharge at Chattanooga were made by a method which was completely independent of daily changes in reservoir volumes. This check method was based on average daily rainfall over the zones into which the total area was divided. Average daily rainfall, in inches of depth over each zone, was computed and converted to units of flow. These flows were then reduced so that the total from all zones was equal to the flood volume at Chattanooga. The sum of the reduced flows for each time interval, allowing for each zone's time lag, was assumed to be the valley inflow for that interval. This valley inflow was then routed to Chattanooga with routing diagrams constructed from the data on pre-reservoir floods. A comparison of crest flows (in cubic feet per second) at Chattanooga in the floods of 1946, 1947, and 1948, as computed from rainfall and by consideration of daily changes in reservoir volumes, is as follows:

Flood	Rainfall	Reservoir volume changes
1946	318,000	320,000
1947	298,000	307,000
1948	307,000	305,000

At least with respect to peak discharge at Chattanooga, this tabulation shows that there is no significant error in using reservoir-volume increments to determine inflows.

A somewhat different check method was used for computing natural discharge at the major tributary dams. Here, the amount of natural valley storage neglected when computing natural discharge from reservoir-volume increments is small compared with the volume of the flood; and, therefore, a more precise method was necessary. In addition to using a time period shorter than one day, the check method consisted of computing valley inflow from: (*a*) The measured discharge at stream gaging stations located above

the influence of the dam; and (*b*) from the rainfall over the unmeasured area between the gaging station and the dam site. The total inflow thus computed was then routed to the dam site with diagrams constructed from data on pre-reservoir floods. A comparison of the two methods showed that there was no significant difference between them, except possibly at Norris Dam, where the peak discharge by the check method was lower and occurred later than did that determined by the reservoir-volume increment method. However, when transferred to Chattanooga, this difference had only a minor effect.

Although a check computation for natural discharge below Chattanooga has not yet been made, the writer feels that natural discharges as now computed for the lower Tennessee River are as accurate as those at Chattanooga. The accuracy of the natural stage at Cairo, of course, is dependent on the accuracy of the discharge computations for the Tennessee River and on the accuracy of the method used to transfer these discharges to Cairo. The writer does not believe, however, that errors would accumulate below the Kentucky dam site, suggested as a possibility by Mr. Linsley, any more than they would on the Tennessee River itself.

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